

Post-AGB evolution much faster than previously thought

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Abstract. For 32 central stars of PNe we present their parameters interpolated among the new evolutionary sequences. The derived stellar final masses are confined between 0.53 and 0.58 M_{\odot} in good agreement with the peak in the white dwarf mass distribution. Consequently, the inferred star formation history of the Galactic bulge is well restricted between 3 and 11 Gyr and is compatible with other published studies. The new evolutionary tracks proved a very good as a tool for analysis of late stages of stars life. The result provide a compelling confirmation of the accelerated post-AGB evolution.

1. Introduction

The main stellar evolutionary tracks for post-AGB evolution are now over 20 years old. Recent results show that they predict the wrong masses and ages for central stars of planetary nebulae (PNe). Gesicki et al. (2014) based on a detailed analysis of 31 Galactic bulge PNe proposed that the post-AGB evolution should be accelerated by a factor of 3. Coincidentally, during the last White Dwarf Workshop, Miller Bertolami (2015) presented new models for the evolution of central stars of PNe obtaining similarly shorter post-AGB timescales on purely theoretical grounds. Here we re-analyse the data sample (recently partially upgraded) however this time we interpolate among the new evolutionary sequences aiming to verify their timescales.

2. Methods and results

The new evolutionary models were published by Miller Bertolami (2016). They included all the recently available improvements to the TP-AGB evolution and are very adequate to the discussion of central stars of planetary nebulae (cspn). In Fig. 1 we show the post-AGB stages of evolution for six new tracks computed for solar metallicity. For comparison we show three old evolutionary sequences from Blöcker (1995) – their slower evolution is apparent.

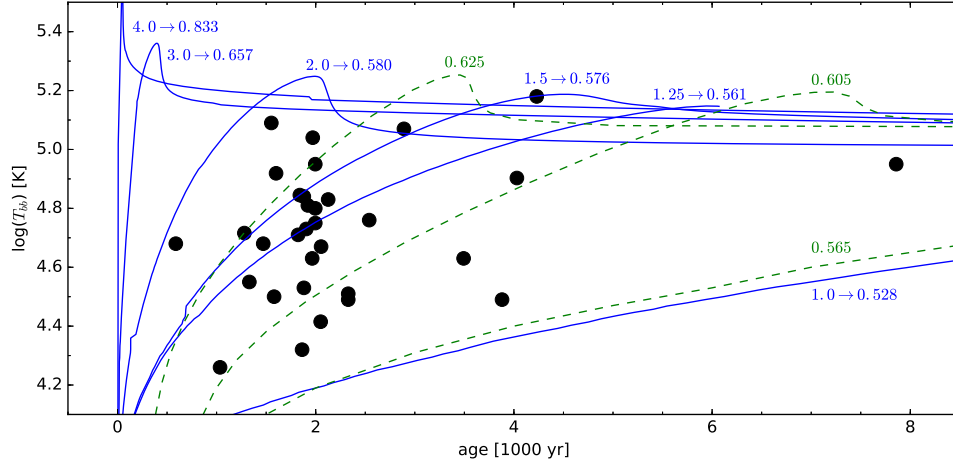


Figure 1. Stellar temperature vs. post-AGB age for the derived data points and for different evolutionary calculations. The solid (blue) lines show the recent evolutionary calculations of Miller Bertolami (2016) for $Z = 0.02$, the lines are labelled with their initial and final masses connected by an arrow. For a comparison the dashed (green) lines show three old evolutionary sequences of Blöcker (1995) labelled with their final mass.

The sample of 31 PNe (Gesicki et al. 2014) was recently partially upgraded after the careful 3D modelling published in Gesicki et al. (2016): one object has been added and parameters of seven others were modified. The parameters derived from photoionization/kinematical reconstruction are: stellar black-body temperature and nebular kinematic age. The 32 data points are shown in Fig. 1. Relating these points with grids of evolutionary models allows for interpolation of stellar masses (both initial and final) and total ages counted from the ZAMS; results are presented in histograms in Fig. 2.

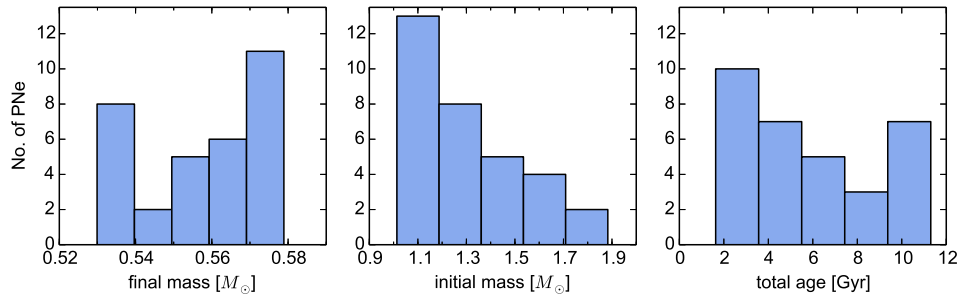


Figure 2. Histograms of cspn final masses, initial masses and total ages. These parameters are derived from the PNe modelling data and the new evolutionary tracks.

3. Discussion

The 32 data points in Fig. 1 represent the most carefully analysed Milky Way bulge planetary nebulae. Because of the limited number of objects, the histograms shown in Fig. 2 are composed of five bins only, equally separated between the extremes.

3.1. Final masses

All derived cspn masses fall within an interval of $0.05 M_{\odot}$ which very often is a single bin for WD mass histograms, see e.g. Tremblay et al. (2016). Therefore the comparison with WD distributions is not perfect, nevertheless all our cspn masses agree with the main peak ($0.55 - 0.60 M_{\odot}$) of the WD masses in the well-studied samples.

The analysed PNe data points cluster in Fig. 1 near post-AGB ages of 2 kyr. The interpolation of Gesicki & Zijlstra (2007) between equally spaced old Blöcker tracks resulted in a distribution sharply peaked at $0.61 M_{\odot}$ while the accelerated Blöcker tracks of Gesicki et al. (2014) show the peak shifted to $0.58 M_{\odot}$. The new tracks of Miller Bertolami (2016) reveal that the area most populated by PNe is traversed by evolutionary tracks of a range of initial (and final) masses. In consequence the obvious peak no longer exists and the final mass histogram (Fig. 2 left panel) is broadened.

3.2. Initial masses and total ages

To derive the initial masses we adopted the theoretical Initial-Final Mass Relation (IFMR) from the new tracks (Miller Bertolami 2016). This IFMR displays a pronounced plateau in the range of masses of interest here, with models of initial masses between 1.25 and $2.0 M_{\odot}$ all ending up with masses between 0.56 and $0.58 M_{\odot}$. This feature is common to many theoretical IFMRs.

About half of our sample falls between the 1.0 and $1.25 M_{\odot}$ tracks (ages above 5 Gyr), while the other half is spread between the tracks corresponding to $1.25-2.0 M_{\odot}$ (ages 5–1.5 Gyr respectively), gradually decreasing towards higher masses. Due to the plateau in the IFMR, the concentration of cspn with masses between 0.56 and $0.58 M_{\odot}$ (Fig. 2 left panel) is spread over a wide range of initial masses (Fig. 2 middle panel). One quarter of the sample has final masses $\sim 0.535 M_{\odot}$, which corresponds to initial masses around $\sim 1.05 M_{\odot}$ and ages of ~ 10 Gyr – these cspn correspond to the peak at very old ages (Fig. 2 right panel).

3.3. Ages and star-formation history

The histogram of total ages was used to derive a star-formation history (SFH). The corrections for PNe visibility-time and for PNe birth-rate were applied exactly as in Gesicki et al. (2014). These corrections suppress the bins at young ages while the old ages bins are enhanced. The resulting SFH is shown in Fig. 3 as a normalized histogram. Obviously there is some uncertainty related with those corrections and their details should be improved in a future.

There is in literature a general consensus that low metallicity bulge stars are older than ~ 10 Gyr while for super-solar metallicity there is no such consensus; different and often contradicting arguments are neatly summarized by Nataf (2016). With the use of chemical evolution models Haywood et al. (2016b) showed that the SFH and the age-metallicity relation obtained for the Galactic inner disk (Haywood et al. 2016a) provided also a best fitting color-magnitude diagram for the Galactic bulge. Their conclusion was that the metal-rich stars of the bulge must be significantly younger than the

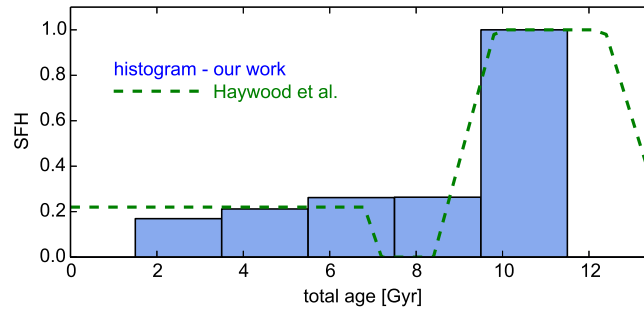


Figure 3. Normalized to unity star-formation-history derived from the histogram of the total ages corrected by PN visibility and birth-rate. The dashed green line shows, for comparison, the SFH derived by Haywood et al. (2016a).

(still dominating) metal-poor population and this is an evidence for the bulge formed through the dynamical instabilities in the disk. Interestingly there is a remarkable similarity between their SFH and ours, both are compared in Fig. 3.

4. Conclusions

The most important outcome of our work are the much lower final masses, as compared with the old models, which is a robust result. The obtained final masses are in good correspondence with the most common white dwarf masses, $\sim 0.55 M_{\odot}$. Our results agree well with the previous suggestion (Gesicki et al. 2014) that the Blöcker (1995) tracks were far too slow. The Galactic bulge SFH, derived from the total ages, points to a burst-like old population, plus some younger objects which is in agreement with the recent Galactic disk SFH and with the idea that the bulge originated from disk instabilities. These numerous accordances constitute a strong support for the short timescales of the new models of Miller Bertolami (2016). The kinematical/photoionization reconstruction method elaborated recently by Gesicki et al. (2016) proved to be efficient.

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